Compiler-guaranteed Safety in Code-copying Virtual Machines

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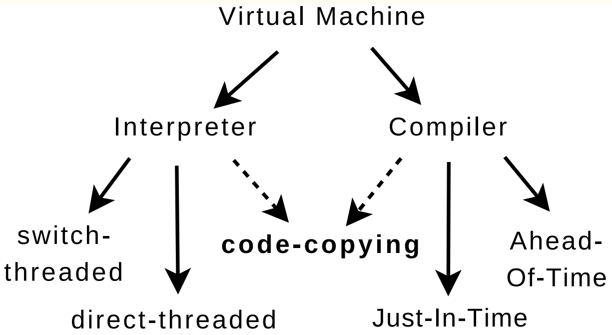
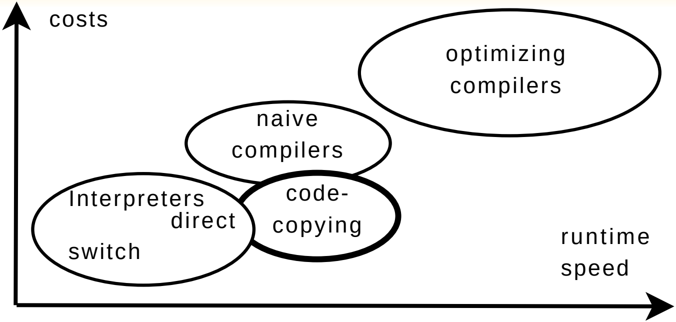
Taxonomy



Code-copying technique

Interpreter and also a JIT.

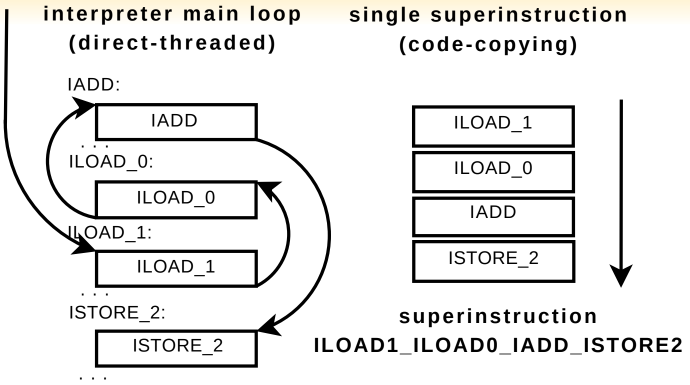
Speed Comparison



Code-copying technique

Bridges the performance gap while keeping costs low.
1.2–3.0 times faster than direct-threading.

Direct-threading vs. Code-copying



Code-copying technique

Reduces number of dispatches and improves branch prediction.

Code-copying Disaster Example

```
BCODE_START:
    if (...)
        {
            // then part
        }
    else
        {
            // else part
        }
```

How it happens?

- Direct-threading - one label

Code-copying Disaster Example

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   if (...)
      {
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      {
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BCODE_END:
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How it happens?

- Direct-threading - one label
- Code-copying - two bracketing labels

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How it happens?

- Direct-threading - one label
- Code-copying - two bracketing labels
- Optimizations move basic blocks

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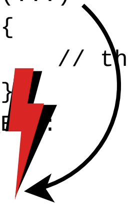
How it happens?

- Direct-threading - one label
- Code-copying - two bracketing labels
- Optimizations move basic blocks
- Incomplete copied code

Code-copying Disaster Example

```
BCODE_START:
   if (...)
      {
          // then part
      }
BCODE_E[illegible]:
   . .

          // else ???
```



How it happens?

- Direct-threading - one label
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- Optimizations move basic blocks
- Incomplete copied code
- CRASH!!!

Code-copying Disaster Example

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How it happens?

- Direct-threading - one label
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- Optimizations move basic blocks
- Incomplete copied code
- CRASH!!!

Problems always arise when a compiler uses relative addressing to reach outside a bytecode.

Motivation

Code-copying

- Easy, cheap to implement
- Great performance
- Not reliable (with modern compilers) - current approaches:
  - Ignore the problem.
  - Hand-check the assembly.
  - Trial and error testing.
  - Approximate runtime checks.

Outline

1. **Background and Motivation**
   - Interpreters vs. Compilers Gap
   - Code-copying and Its (Lack of) Safety
2. **Our Design and Implementation**
   - Copied Code Tracking
   - Verification
3. **Results and Conclusions**
   - Performance
   - Compiler Maintainability Impact

Copyable Code - What Is It?

Copyable Code "Chunk" Requirements

- Contiguous in memory between two labels
- Control flow "top" to "bottom"
- Jumps to outside and calls are absolute
- Jumps within chunk are relative
- Consistent registers use at entry and exit

Solution overview

Optimizing compiler (GCC) enhancement

- Programmer-friendly #pragma
- Track copyable code "chunks"
- Dozens of passes — Do not touch!
- Selective restore of code properties
- Final code verification

Solution overview

Inserted new passes

- Identify basic blocks of copyable code chunks
- Enforce absolute jumps and calls
- $\Rightarrow$ Run existing optimizations
- Basic block order fixup
- $\Rightarrow$ Legacy existing optimizations
- Copyable code verification

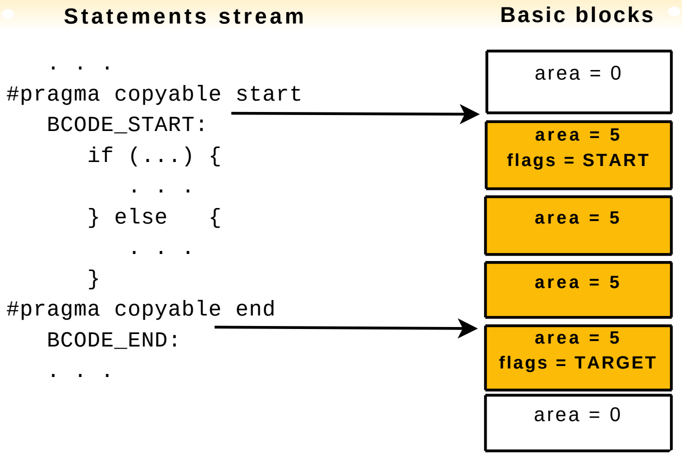
Pragma Handling

```
. . .

BCODE_START:
   if (...) {
      . . .
   } else   {
      . . .
   }

BCODE_END:
. . .
```

Pragma Handling

```
   . . .
#pragma copyable start
   BCODE_START:
      if (...) {
         . . .
      } else   {
         . . .
      }
#pragma copyable end
   BCODE_END:
   . . .
```

Pragma Handling



First and past-last basic blocks are marked as Start and Target.

Enforcing Absolute Gotos and Calls

```
BCODE_START:
   . . .
   if (ptr==NULL)
     goto NPE_handler;
   . . .
BCODE_END:
```

Need to correct relative addressing within "chunks".

- External assembler decides on addressing mode — not GCC.
- Needed an architecture-agnostic solution.

Enforcing Absolute Gotos and Calls

```
BCODE_START:
   . . .
   if (ptr==NULL)
     goto NPE_handler;
   . . .
BCODE_END:
```

```
{  void *target = &NPE_handler;
   __asm__ __volatile__ (
      ""             :
      "=r" (target) :
      "0"  (target) :
      "memory");
   goto *target;
}
```

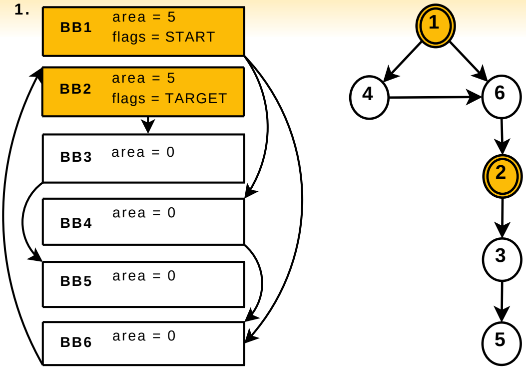
Need to correct relative addressing within ”chunks”.

- External assembler decides on addressing mode — not GCC.
- Needed an architecture-agnostic solution.
- Goto to the outside of chunk is forced into a computed goto.
- Each call is forced into call via function pointer.

Compiler Runs Largely Unaffected

- Once Start and Target basic blocks are marked and absolute addressing enforced all optimizations are performed as usual.
- A lot of work to modify several dozens of passes — don't!
- Start and Target block are never removed or duplicated.
- Able to find all copyable code of each chunk via CFG.
  - Traverse CFG from Start until Target or computed goto is reached.
  - No heuristics.

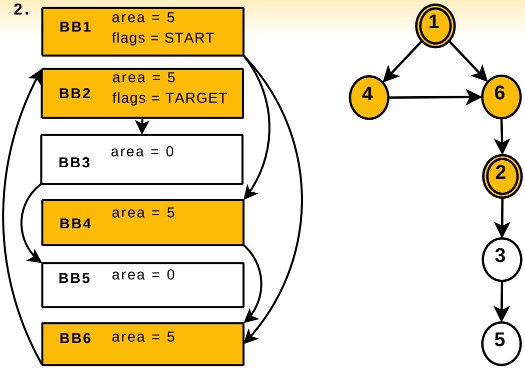
Ensuring Copyable Code Contiguity



1. Compiler moved basic blocks.

Ensuring Copyable Code Contiguity

2.



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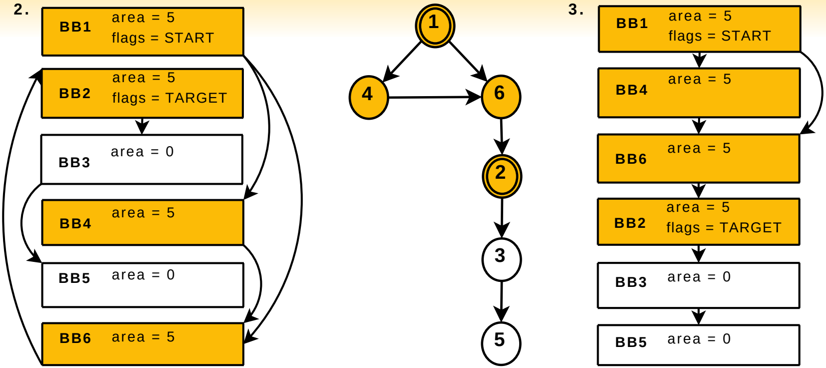
Ensuring Copyable Code Contiguity



1. Compiler moved basic blocks.
2. Follow CFG to find blocks of each chunk.
3. Reorder basic blocks, deoptimize to ensure chunk contiguity.

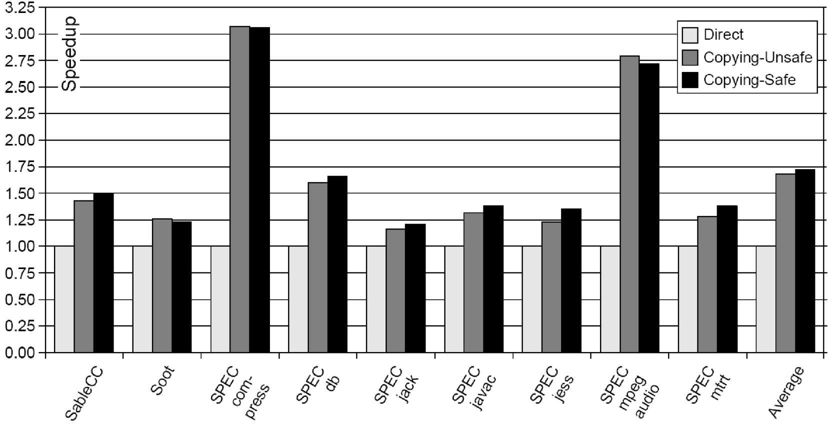
Final Verification Pass

- CFG is discarded at some point.
- Some legacy optimization code is ran after.
- Need to be sure of the final result.
- Insert special RTL "notes" to mark Start and Target.
- When the code is final verify all properties.
- This way ensure safety of the final result.

Brief Design Summary

- Enables **safe** code-copying.
- Avoided modifying dozens of passes.
- Very maintainable.
- Easy to use.
- Portable.

Performance Comparison



Comparable or faster than unsafe code-copying of SableVM JVM

Compiler Maintainability Impact

Metric	#
Data structures modified	4
Fields added to data structures	6
Data structures added	3
Functions added to existing files	4
Function calls/hooks inserted	8
Code lines added or modified	139
Code lines in new files	1500

- Minimal impact in terms of source modified.
- Update GCC 3.4 to 4.2 (2 years of development) took only a few hours.

Conclusions and Future Work

- Presented an industry compiler extension supporting copyable code generation.
- Easy to use by VM programmers.
- Easy to maintain in the compiler.
- Provides safety guarantees for copied code execution in a VM.
- Provides comparable performance to unsafe copied code execution.

- Expected future application to other VMs and other architectures.

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Questions?